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ORIGINAL RESEARCH

Assessment of the domestic energy use impacts of unplanned refugee settlements on the forest ecology of Cox's Bazar, Bangladesh

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Abstract – This study monitors the forest ecology in Himchari National Park, Teknaf Wildlife Sanctuary, and between the areas in Cox's Bazar district, Bangladesh. The area has a rich biodiversity, including globally endangered species such as Asian Elephants (*Elephas maximus*) and Boilam Trees (*Anisoptera scaphula*), which are threatened by anthropogenic development, newly refugees' unplanned settlements and their use of domestic energy. Geographic Information System (GIS) and Landsat satellite images are used to monitor forest coverage for 1995–2018. The Normalized Difference Vegetation Index (NDVI) is applied to quantify forest area. Focus group discussions and questionnaire surveys were conducted to reveal stakeholder perceptions about their dependency on forest resources as ecosystem services. Close to the refugee camp areas, the forest coverage changes to grassland due to the unsustainable forest resource extraction. Despite the free of charge supply of Liquefied Petroleum Gas, the refugees burn 2,380 metric tons of firewood every month to satisfy energy for cooking. Besides, 200,000 households frequently use bamboo, small trees, and shrubs to maintain their dwellings' structure. Thus, deforestation caused by immigration between 2017–2018 is similar to that caused by the effect of climate change, including severe tropical cyclones in 1994–1995. This research identifies domestic energy supply deficiency and impacts, and the need for comparatively durable housing materials to reduce stress on forest resources and health hazards.

Keywords – Unplanned refugees' settlement, Forest ecology, GIS and Remote sensing, Gender-specific stakeholders' perceptions

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INTRODUCTION

Much has been written on Rohingya refugee migration from Myanmar to Cox's Bazar in Bangladesh, and its effects on the forest of the Teknaf Wildlife Sanctuary (TWS) (Fig. 1) (e.g., Belal, 2013; Braun et al., 2019; Hassan et al., 2018; Islam et al., 2019; Khan et al., 2012; Rahman et al., 2012, 2014, 2019; Sakamoto et al., 2017; Tani et al., 2014; Uddin and Khan, 2007; Uddin et al., 2013) . The forced migration of Rohingya refugees from Myanmar to Bangladesh; 222 000 in 1978, 250 000 in 1991–92, 144 257 in 1994–95, and 87 000 in 2016, can be described as ethnic cleansing (Azad and Jasmin, 2013; Grundy-Warr and Wong, 1997; Reid, 2020). However, a massive influx of people has happened almost every year since the early 1990s (Table 1), with some people returning to their homeland Myanmar in 1979 and 1992-93 (Table 1). During 1992–93, 30 000 refugees escaped the camps, mingled with the local population in Bangladesh, and migrated to third countries (Table 1). Estimates suggest an influx of 742 000 refugees in three months, from September to November 2017 as a result of ethnic cleansing operations by Myanmar military forces (UNHCR, 2018, 2019; ISCG, 2019; OCHA, 2020).

About 70% of these refugees settled at Site A (Kutupalong, Ghumdhum, Balukhali), and ~11% at Site B (Thaingkhali) (Fig. 1) (ISCG, 2019). The remaining 19% of refugees have settled in different small areas, including mixing with local people such as in Site C (Fig. 1). Only ~16% of refugees live in 6 camps out of 34 that are located near to or in the vicinity of Teknaf Wildlife Sanctuary (TWS) (Fig. 1) (ISCG, 2019). Site A, where the highest percentage (~70%) of refugees settled, is located between the TWS and Himchari National Park (HNP) (Fig. 1). This study puts equal importance on investigating the forest ecology of the HNP and the TWS, including the Rohingya Refugee Camp Area (RRCA) in Cox's Bazar District (Fig. 1).

A combination of methods of remote sensing techniques and Geographic Information Systems (GIS) is commonly used to explore details about forest ecology globally (e.g., Hadi et al., 2018; Trier et al., 2018) and in Bangladesh (e.g., Braun et al., 2019; Imtiaz, 2018; Islam et al., 2019; Islam, 2014). In this combined method, the Normalized Difference Vegetation Index (NDVI) (Campbell, 2002, p. 466) is applied. This study integrates remote sensing analysis with stakeholder perceptions to investigate: the use of ecosystem services; reasons for ecological change; and impacts on forest ecology around the Rohingya refugee unplanned settled area in Cox's Bazar, Bangladesh.

CHARACTERISTICS OF THE STUDY AREA

The study area is situated between ~91°59′53″ E – 92°20′58″ E and ~20°44′52″ N – 21°24′13″ N, a forest ecological zone in the south-eastern district of Cox's Bazar in Bangladesh (Fig. 1).

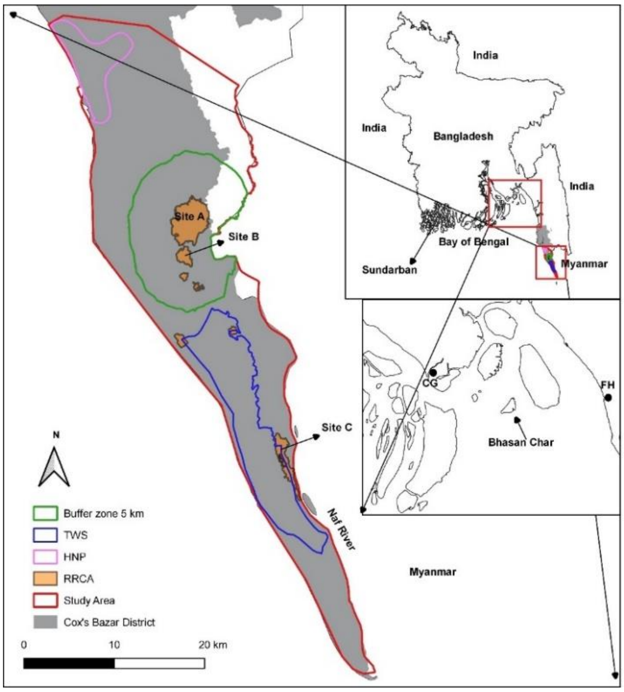

Figure 1. Study area with some important features. The arrows indicate particular sites. Black dots locate Chairman Ghat (CG) and Faujdarhat (FH) mainland river ports. Location of Teknaf Wildlife Sanctuary (TWS), Himchari National Park (HNP), Rohingya Refugees Camp Areas (RRCA), and 5 km buffer of Site A and Site B of RRCA is also illustrated.

Table 1. The annual influx of Rohingya refugees to Bangladesh summarized from (Grundy-Warr and Wong, 1997; Azad and Jasmin, 2013; UNHCR, 2019; OCHA, 2020; Reid, 2020).

Year	Number of refugees	
	Influx in Bangladesh	Return to Myanmar
1975	3 500	
1978	222 000	
1979		187 250
1991-92	250 000	
1992-93		50 000; 30 000*
1994	82 753	
1995	61 504	
1996	23 504	
1997	10 073	
1998	106	
1999	1 128	
2000	1 323	
2001	283	
2002	760	
2003	3 231	
2004	210	
2005	92	
2016	87 000	
2017	742 000	
2018	12 000	

* Refugees left the camps and, either mingled with the local people or migrated to third countries.

This area is ~74 321 ha and consists of HNP, TWS, and RRCA in Cox's Bazar, Ukhiya, Ramu and Teknaf sub-districts of Cox's Bazar district in Bangladesh, between the Naf River and Bay of Bengal (Fig. 1). The boundary of HNP is defined as shown in Fig. 1 (Google Earth, 2020). The area and location of TWS are adopted from Alam et. al. (2015) and Islam et al. (2019) (Fig. 1). The boundary of RRCA is adopted from ISCG (2019) and OpenStreetMap Foundation (2018) (Fig. 1).

It is a hilly area with a tropical climate. The soil characteristics vary from clay to clayey loam on the low ground and sandy loam to coarse sand on hilly land with 31-40% porosity, strongly acidic, with medium organic matter (Islam et al., 2017). The elevation ranges from -30 m (below sea level) up to 369 m with a gentle slope. The monthly average temperature is 15 °C in the winter and 32 °C in the summer, with humidity ranging from 27% to 99% (Alam et al., 2015; Islam et al., 2019; Khan et al., 2012). The monthly average rainfall is 349.4 mm. However, there are frequent heavy rainfalls (up to 940 mm per month) in the monsoon (May–October) and a dry off-monsoon season (Khan et al., 2012; Uddin et al., 2013).

The HNP lies between ~91°59′59″ E – 92°5′15″ E and ~21°17′42″ N – 21°23′54″ N along the coast of the Bay of Bengal between the TWS and the Cox's Bazar district town with three blocks of the forest; Bhangamura Reserve Forest, Chainda Reserve Forest and Jhilongja Protected Forest (Fig.

1) (Hossen and Hossain, 2018). It is a National Park (since 1980), covering 1 729 ha where ~550 ha is protected as undisturbed tropical mixed evergreen forest. It is full of biodiversity, including 127 species of birds, and globally critically endangered Asian Elephants and Boilam Trees (*Anisoptera scaphula*) (Nishorgo, n.d.-a).

The area of TWS is 11 615 ha. It was designated as Teknaf Game Reserve in 1983, and in 2009, the Govt. of Bangladesh enhanced it's status to a protected Wildlife Sanctuary (Nishorgo, n.d.-b). This reserve forest is ~29 km long and ~2–6 km wide and runs along the coast of the Bay of Bengal, lying between ~92°8′30″ E – 92°17′53″ E and ~20°51′58″ N – 21°6′45″ N (Fig. 1). The ecosystems of this area are degraded but remain very biodiverse. They include mangroves, hilly rain forests, and sand dunes (Uddin et al., 2013). This area supports 535 species of plants, including many indigenous species; and 613 species of animals, including Asian elephant (*Elephas maximus*) (Belal, 2013; Mannan, 2017; Uddin et al., 2013).

MATERIALS AND METHODS

Remote sensing data sets

This study uses remote sensing data downloaded from USGS (https://earthexplorer.usgs.gov/) (United States Geological Survey-USGS, n.d.), which covers the dry seasons (November–December) (Table 2). The data sets are georeferenced by the European Petroleum Survey Group with the following characteristics; Projection: Transverse Mercator, Projection Coordinate System: WGS 1984 UTM Zone 46N, Linear Unit: Meters. Details of satellite data and other data sets are provided in Table 2. Bands 3 (green), 4 (red) and 5 (near-infrared) for Landsat 8, and bands 2 (green), 3 (red) and 4 (near-infrared) for Landsat 4-5 are used. Spatial resolution of used data set is 30 m. The spectral resolution for Landsat 8 is 0.53–0.59 µm (green), 0.64–0.67 µm (red), 0.85–0.88 µm (near-infrared) and for Landsat 4-5 is 0.52–0.60 µm (green), 0.63–0.69 µm (red), and 0.76–0.90 µm (near-infrared).

Image pre-processing

Remote sensing depends on the observed spectral difference in reflected and/or emitted energy from features of interest. As required to address in Table 1, the remotely sensed images were acquired for different years. Similar land covers could have different levels of reflection and/or radiation over time due to satellite sensor calibration, spatial differences, different spectral resolution and signatures, illumination and observation angle and/or changes in the field of view over the earth surfaces, atmospheric effects of scattering and different orientation of target objects (Du et al., 2002; Islam, 2014). The different Digital Numbers' (DNs) values in different year's images represent similar land cover because of the mentioned factors, which have a further effect on NDVI, if the DNs value of input image is not corrected. Guyot and Gu (1994) found a difference in the NDVI value of -0.1 between radiometric corrected and non-corrected Landsat TM data. Therefore, to minimize this effect, radiometric correction was performed. Although many researchers have ignored this correction to calculate NDVI in their studies (e.g., Imtiaz, 2018), this study has conducted Relative Radiometric Normalization (RRN) (de Carvalho Júnior et al., 2013) by applying a linear regression method before NDVI calculation as outlined in other studies (e.g., Govaerts and Verhulst, 2010; Islam, 2014).

For RRN, roads, the runway of an airport, freshwater (lakes and ponds), saltwater (sea, estuarine water, and lagoons), vegetation (specifically forest area), dry sands, and bare soil (fallow land), remain unchanged over time in the image pairs and are selected as pseudo-invariant features (PIFs) (Bao et al., 2012; de Carvalho Júnior et al., 2013). Images from 1995, 2014, and 2018 are considered for correction based on images from 2016, as with image pair 2016-1995, 2016-2014, and 2016-2018. To identify PIFs, images in different years are visualized as False Colour Composition (FCC) (Fig. 2) (Manugula and Bommakanti, 2017; Patra et al., 2006) where green, red and near-infrared (Table 3) are set to blue, green and red channels, respectively applying the Imagery Composite Bands tool of ArcGIS Pro 2.4.3 (ESRI, 2019). A shapefile (point) is created where more than 500-600 point features from PIFs in image pairs are generated. The tool "Add grid value to shape" of System for Automated Geoscientific Analysis (SAGA) GIS 2.3.2 (Conrad et al., 2015) is applied to save those PIF's pixel values in point features. Microsoft Excel 2016 is then used for scatter plot and linear regression analysis. Table 3 shows the correlation coefficient (R^2) with a linear regression equation. The RRN was generated as shown in the equations in Table 3 using Raster Calculator in ArcGIS Pro.

Table 2. Details of used data sets.

Satellite data Program/Sensor	Path	Row	Acquisition date	Data type	Source
Landsat 8 OLI/TRIS C1 Level -1	136	45	31 Dec 2018	GeoTIFF	USGS, n.a.
Landsat 8 OLI/TRIS C1 Level -1	136	45	23 Nov 2016	GeoTIFF	
Landsat 8 OLI/TRIS C1 Level -1	136	45	18 Nov 2014	GeoTIFF	
Landsat 4-5 TM C1 Level -1	136	45	16 Dec 1995	GeoTIFF	
Other data					
Rohingya refugees camp location and population			30 Jun 2019 (pb)	pdf	ISCG, 2019
OpenStreetMap (URL: https://tile.openstreetmap.org/{z}/{x}/{y}.png)					OpenStreetMap Foundation, 2018
Terrain Map (URL: http://mt0.google.com/vt/lyrs=p&hl=en&x={x}&y={y}&z={z})					Google Earth, 2020

Table 3. The correlation coefficient of linear regression analysis.

Equations	Correlation coefficient (R^2)	Used images
y = 238.98x + 3279.2	0.88	y = NI in 2016, x = NI in 1995
y = 127.00x + 5132.2	0.73	y = RD in 2016, x = RD in 1995
y = 1.0776x - 1016.9	0.96	y = NI in 2016, x = NI in 2014
y = 1.1243x - 934.6	0.92	y = RD in 2016, x = RD in 2014
y = 1.2941x – 1930.5	0.96	y = NI in 2016, x = NI in 2018
y = 1.2830x – 1903.1	0.93	y = RD in 2016, x = RD in 2018

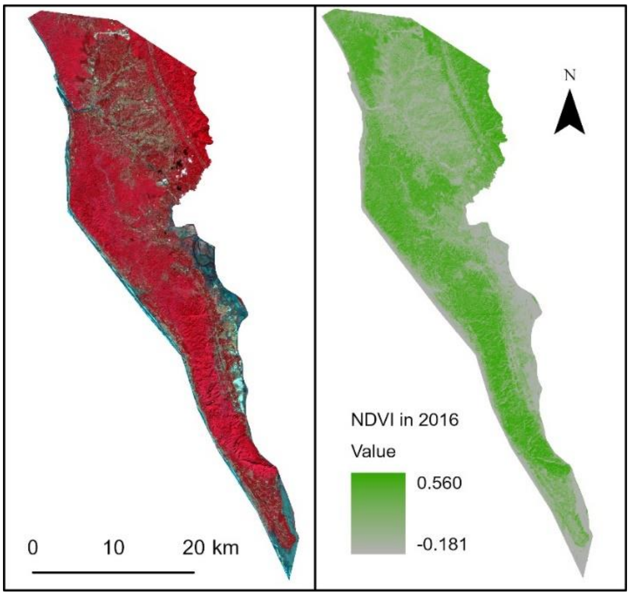

Figure 2. The study area in False Colour Composition (FCC) (left) and calculated NDVI in 2016 (right).

Normalized Difference Vegetation Index (NDVI)

NDVI is calculated as Imtiaz (2018), Islam (2014) and Jackson et al. (2004):

$$NDVI= (DN_{NIR} - DN_{RED}) / (DN_{NIR} + DN_{RED}) \quad \text{eq. 1}$$

Where DN_{NIR} is the DN value of the near-infrared band and DN_{RED} is the value of the red band. The NDVI is executed as shown in equation 1, applying Raster Calculator in ArcGIS Pro similar to the RRN application.

Reclassification and land cover quantification

The NDVI layer is reclassified as per the scheme; water = <=0, non-forest = 0-0.2, grassland = 0.2-0.3, and forest = >0.3. The reclassification is based on studies by (Imtiaz, 2018; Islam, 2014; Weier and Herring, 2000). In this reclassification scheme; water covers clean and turbid water, rivers, ponds, lakes, and seawater, non-forest includes all types of land cover between water and grassland, e.g., roads, built-up areas, open land, and so on, and the bushy areas are included in grassland land cover. A majority filter with eight-neighbours (a 3X3 kernel filter) (Heywood et al., 2006) is applied as per similar methodologies to smooth the reclassified land cover layer (Acevedo and Jones, 2012; Enderle and Weihjr, 2005). This reclassification scheme is level-I (e.g., water, forest, non-forest) and can be classified without ancillary data, using visual interpretation (Thompson, 1996). The reclassified layers are assessed where approximately 100-150 points feature of each class is generated by visual interpretation from FCC format original images. Similar to the RRN, the grid value of reclassified layers are extracted and estimated for overall accuracy, dividing the total number of correctly reclassified grids by the total number of test grid/point features which results in the overall accuracy of image classification estimate of 91% for the images in 1995, 94% for the images in 2014 and 2016, and 95% for the 2018 images.

Further, the area of land cover is calculated by multiplication of pixel resolution and the number of pixels and then converted to hectare (ha). The areal calculation is conducted based on mask area; overall, in the study area, and for detailed investigation in the: TWS, HNP, and in the 5 km buffer of RRCAs where more than 80% of the refugees live.

Refugees' settler's perceptions of forest dependency

Much research has been conducted on the dependence of the impoverished local people and the refugees who migrated before the 2017 influx on forest resources in the area (Alam et al., 2015; Belal, 2013; Sakamoto et al., 2017). Therefore, this study only focuses on the influx of refugees during 2017 and considers their dependency on forest resources using a qualitative approach. A reconnaissance survey (Faircloth, 2017) to the Kutupalong and Balukhali Expansion Sites (Site A in Fig. 1), was carried out by the lead author (M.T. Islam) in August 2018, which revealed the general dependency of refugees on nearby forestry resources. To understand the refugees' perceptions and use of natural resources to provide energy for domestic services such as firewood for cooking, focus group discussions (FGDs) (Nyumba et al., 2018) were undertaken between 17-19 April 2020 in the same area (Nyumba et al., 2018). It was found that female refugees are mainly involved in household activities, like cooking and making choices on how to prepare food with available fuels, and males are involved in outdoor activities as well as controlling overall affairs regarding their family. Therefore, to understand the detailed view of gender-specific perceptions on efficient use of household fuel energy, a structured questionnaire survey was conducted from 09-15 June 2020 in the same area among 32 households, where 22 respondents were females who cook daily for their family, and 10 respondents were males who lead their family. A separate semi-structured questionnaire survey was also conducted during this time (09-15 June) with the firewood sellers in the camp area.

RESULTS

Quantitative measures: Land cover changes

As estimated by the analysis of Landsat remote sensing imagery over the study area (Figs. 1; 3), the areal coverage of water over the years since 1995 is almost constant, 2.2%-3.2% (Table 4; Fig. 3). Non-forest decreases from 22.5% in 1995 to ~9.5%–11% in 2014–2016. Then, it increases to 17% in 2018. The forest land increases from 55.1% in 1995 to ~71% in 2014–2016 and then decreases to 60.5% in 2018. The area covered by grassland remains more constant of ~20% coverage in 1995 and 2018 (Table 4; Fig. 3).

At the Himchari National Park (HNP) (Fig. 1), water coverage is not significant and remains unchanged during 1995-2018 (Table 4; Fig. 3). The non-forest decreases from 4% in 1995 to ~2% in 2014–2016 and then increases to 3% in 2018. The grassland falls ~4% from 1995–2014 and then increases by ~4% in 2018. Forest area increases ~6% from 1995–2014 and decreases by ~3% in 2018 (Table 4; Fig. 3). All types of land cover remain the same during 2014–2016.

The total area of Teknaf Wildlife Sanctuary (TWS) is identified as 11 218 ha (Table 4). Water coverage is not significant over the study period 1995–2018 (Table 4; Fig. 3). The non-forest and grassland land cover are decreased, respectively ~5% and ~9% from 1995 to 2014–2016. However, the grassland increases by 4.7% during 2016–2018 (Table 4). The forest area rises from 78.3% in 1995 to ~92%-93% in 2014–2016 and then falls to 87.4% in 2018. All types of land covers remain unchanged during 2014–2016 (Fig. 3).

With the 5km buffer of the Rohingya Refugees Camp Areas (RRCA), water coverage is almost insignificant during the study period 1995–2018 (Table 4; Fig. 3). The non-forest decreases from 13.6% in 1995 to 3.6% in 2014 and then increases to 20% in 2018. The grassland decreases from 18.2% in 1995 to ~15% – ~16% in 2014–2016 and then rises to 23.4% in 2018. The forest area increases from 67.7% in 1995 to 80.7% in 2014 and then decreases to 78% in 2016 and 56% in 2018.

Qualitative measures: Refugees settlers' perceptions

The refugee camps in Cox's Bazar are protected by the security forces of Bangladesh, and the refugees are not allowed to work or go out of the camp area without permission. The average housing area for the refugee's in the camps is ~16–22 m^2 (Fig. 4a). The structure of these houses is mainly bamboo-based (Fig. 4a). Wooden and small tree-structured houses were also observed. Materials are supplied by the UNHCR and Government of Bangladesh free of charge.

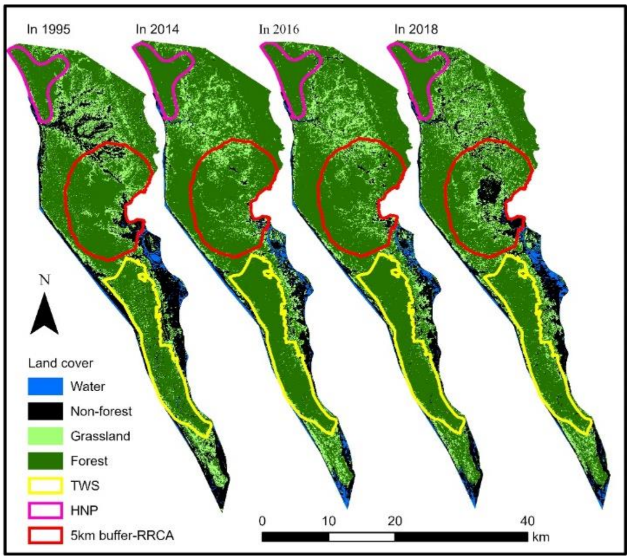

Figure 3. Land cover in different years over the study area in the Cox's Bazar, Ukhiya, Ramu and Teknaf sub-districts of Cox's Bazar district in Bangladesh.

Table 4. Land cover changes over time in the study area of 74 320 ha, in the Cox's Bazar, Ukhiya, Ramu and Teknaf sub-districts of Cox's Bazar district in Bangladesh.

Area	Year	Water (ha)	Non-forest (ha)	Grassland (ha)	Forest (ha)
All study area	1995	1 639 (2.2%)	16 721 (22.5%)	15 000 (20.2%)	40 960 (55.1%)
	2014	2 410 (3.2%)	7 081 (9.5%)	11 719 (15.8%)	53 111 (71.5%)
	2016	1 831 (2.5%)	8 168 (11.0)	11 686 (15.7%)	52 635 (70.8%)
	2018	1 878 (2.5%)	12 632 (17.0%)	14 820 (19.9%)	44 991 (60.5%)
HNP	1995	8 (0.2%)	165 (4.0%)	353 (8.5%)	3 611 (87.3%)
	2014	10 (0.3%)	83 (2.0%)	167 (4.0%)	3 877 (93.7%)
	2016	9 (0.2%)	86 (2.1%)	182 (4.4%)	3 859 (93.3%)
	2018	6 (0.2%)	124 (3.0%)	261 (6.3%)	3 745 (90.5%)
TWS	1995	32 (0.3%)	772 (6.9%)	1 604 (14.3%)	8 811 (78.3%)
	2014	1(0.0%)	191 (1.7%)	671 (6.0%)	10 355 (92.3%)
	2016	1 (0.0%)	233 (2.1%)	559 (5.0%)	10 425 (92.9%)
	2018	1 (0.0%)	324 (2.9%)	1 085 (9.7%)	9 809 (87.4%)
5 km buffer of RRCA	1995	70 (0.4%)	2 239 (13.6%)	2 996 (18.2%)	11 142 (67.7%)
	2014	64 (0.4%)	588 (3.6%)	2 516 (15.3%)	13 279 (80.7%)
	2016	30 (0.2%)	866 (5.3%)	2 715 (16.5%)	12 836 (78.0%)
	2018	94 (0.6%)	3 289 (20.0%)	3 855 (23.4%)	9 209 (56.0%)

The bamboo comes from the nearby district, e.g., Bandarban and trees can be collected from Cox's Bazar and other nearby districts. The bamboo and small trees are not durable, and therefore, refugees often change the structure of their houses on their own. UNHCR provides housing maintenance materials once annually. The houses consist of an indoor kitchen and bathing place for women (Fig. 4b). Men and children use communal bathing places outside their homes, and everyone uses communal toilets (Fig. 4c-d).

The field survey of 32 households revealed an average family size of 5.75 people per household, where 3 people are adults. UNHCR provides 12 kg of rice, four kg of pulses, one litre of cooking oil, half a kg of sugar, and some spices per person as a ration. Alternatively, they were given 770 Bangladeshi Taka (BDTK) (~US$ 9) per person per month as an e-voucher that could be used to buy provisions in predefined shops; however, this scheme is no longer in place. They do not get any fish or vegetables in their food menu (Fig. 4e-f).

(a) (b) (c) (d) (e) (f)

Figure 4. Rohingya Camps area in Cox's Bazar; (a) House, (b) indoor bathing place, (c) communal outdoor bathing place (d) communal toilet, and (e, f) fish and vegetable market in the Rohingya Camps area in Cox's Bazar.

Figure 5. Fuelwood selling shop in the Rohingya Camps area in Cox's Bazar.

Among the 32 households, 22 households (~69%) have no income. The other 10 households (~31%), whose family members temporally work, e.g., in the local *madrasa* (Islamic education institute), local and international non-government organization and informal business, have BDTK 1 755 (~US$ 20.7) average monthly income. But that is not enough to buy fish, vegetables, other provisions, healthcare, and fuel for cooking. Therefore, they sell part of their ration, their primary income source, this is a health hazard because of malnutrition (Malhotra, 2018).

UNHCR provides Compressed Rice Husks (CRH), Liquefied Petroleum Gas (LPG) cylinders (12.5 kg gas), and Stoves for almost every household free of charge (the local market price is ~1 250 BDTK (~US$ 14.7) per cylinder) under the condition that (i) they will not collect firewood, (ii) will not sell the LPG cylinders, (iii) will not permit young children to cook, and (iv) will use the gas responsibly and only as instructed by the safety training. An LPG cylinder is provided to a family for 28 to 47 days according to the family size; 45–47 days for one person, 40–43 days for 2– 3 person, 35 days for 4–5 person, 32 days for 6–7 person, and 28 days for 8–10 person family.

The LPG is only used for cooking. One out of 32 households sometimes uses it for boiling drinking water for the children. Females cook food for 31 households surveyed, and there is only one household where males cook food because it is a one-person household. 26% of females who cook food for their families have no institutional education, and 71% of females have primary education. The average time spent cooking is about one hour 40 minutes/day/household. However, almost every family faces a deficiency of LPG for 7–12 days/month. When the LPG is finished or going to end, the household women who are responsible for cooking tell their men about the situation. The men are expected to resolve this. 34% of households use firewood, and the remaining 66% refill LPG from the local market at their own expense to fill the deficiency. Considering all households (32), the average expenditure for cooking fuel is BDTK 72 (~US$ 0.85) per person per month. This cost is ~25.5% of the households' monthly income for those with little income generation.

Males transport the LPG cylinders to be refilled and buy firewood using a man-powered van (*Van Gari*). This also happens in female-headed households if any man or boy is available to bear this responsibility. Otherwise, the family hires a man for transportation. Any kind of trees that come to the market can be used as firewood, but Akashmoni (*Acacia auriculiformis*) trees are preferred (Fig. 5). Perceptions are that firewood is mainly leftovers from processing timber which are collected, transported, and marketed by local people. However, the shape and size of the bundles available at the market suggest that some is purposely collected and processed for firewood (Fig. 5). After repairs to their house, waste materials (bamboos and trees) are used for fuel. Everyone prefers to use LPG for cooking in the camps because only indoor cooking is allowed in the camps. Air pollution from other fuels creates a problem indoors and for neighbours. A respondent said, "I have seven members in my family and get an LPG cylinder for 32 days. But it serves only for 20 days and the remaining 12 days we depend on firewood for cooking".

DISCUSSION

This study has evaluated land cover change, specifically changes in forest ecology using Landsat satellite imagery with 30m pixel resolution (Table 2). The results show that land cover has changed over time throughout the study area. Notably, in 1995, the coverage of non-forest and the grassland was 22.5% and 20.2%, respectively, higher than in 2014–2016 (Table 4; Fig. 3). Forest cover increased by ~16% from 1995–2014, but it remains unchanged between 2014 and 2016. Severe tropical cyclones which made landfall in the study area in 1991 (wind speed: 235 km hr^{-1}, storm surge: 8.8 m), 1994 (wind speed: 190 km hr^{-1}, storm surge: 4.9 m), and 1995 (wind speed: 110 km hr^{-1}, storm surge: 3.6 m) may be responsible for the comparatively lower area of forest cover in 1995, compared with 2014-2016 (Alam et al., 2020;

Dasgupta et al., 2010). Assessment of similar event, when 22% of Sundarbans mangrove forest (south-western, Bangladesh, Fig. 1) was damaged by severe tropical cyclone, "Sidr", 2007 (wind speed: 250 km hr^{-1}, storm surge: 6-8 m) estimates forest cover recovery time to be approximately 25 years, based on remotely sensed Landsat satellite imagery since 1975 (Islam, 2014). However, non-forest cover increases of 1.5% during 2014–2016 and 6% during 2016–2018, and grassland cover remaining unchanged during 2014–2016 but increasing by 4.2% during 2016–2018 (Table 4; Fig. 3) appear directly linked to the unplanned settlement of refugees in this area. Within three months, (September–November 2017), 742 000 refugees arrived from Myanmar (Table 1). Within the study period (September 2017-December 2018), 754 000 refugees were living at the refugee camps, with more than 80% living at Site A and Site B in the Rohingya Refugees Camp Area (RRCA) (ISCG, 2019; Fig. 1). Note that the difference in the forest cover in the study area between 1995 and 2018 is ~5% (Table 4). The sum of non-forest and grassland cover was 42.7% in 1995 and 36.9% in 2018. This indicates that the forest degradation caused by the unplanned settlement of newly arriving refugees may be similar to the effects of the severe tropical cyclones during 1991–1995. Now the days, more intense tropical cyclones are associated because of climate change effects (Wang, 2015; Knutson et al., 2020). It leads to severe damage to forest coverage when it makes landfall and passes through a forest land, e.g., tropical cyclone in 1991 at the forest area in Cox's Bazar region (Alam et al., 2020) and Sidr in 2007 at Sundarbans in Khulna-Bagerhat region (Islam, 2014).

The area of the Himchari National Park (HNP) is demarcated to 4 136 ha (Fig. 1) reference to Google Terrain map (Google Earth, 2020), which is about twice the area for HNP given by Nishorgo (n.d.-a) which is a network and works for co-management with the local community, government and other stakeholders. This might be a limitation of this study not obtaining a clear boundary of HNP in secondary sources. But, it is expected that this study provides an overall picture of the forest ecology of the HNP and for detailed study, a well-defined boundary is required. However, at the HNP area, non-forest increases over time, 2% in 2014, 2.1% in 2016, and 3% in 2018 (Table 4; Fig. 3); grassland cover increases of 4% in 2014, 4.4% in 2016, and 6.3% in 2018; and forest area decreases of 93.7% in 2014, 93.3% in 2016, and 90.5% in 2018, may not be directly linked to the new influx of refugees. This is because the HNP is situated outside of the 5 km buffer of the RRCAs (Fig. 1) - this study revealed that people are not allowed to leave the RRCAs to collect firewood or other resources from the HHP. However, the HNP contains more than 4 000 households, including Rohingya refugees who migrated since the early 1990s. Poverty is high, with subsistence dependency on conversion of forest to agricultural uses (Hossen and Hossain, 2018; Nishorgo, n.d.-a), and economic dependency on cutting and collecting forest resources (e.g., timber, firewood, bamboo, fence posts, non-timber forest products such as fruits and grasses) which are sold at the RRCAs to fulfil the identified gaps in domestic energy and building materials supply.

Estimated green coverage (forest together with grassland) in Teknaf Wildlife Sanctuary (TWS) was 10 984 ha before the influx of refugees in 2016-2017 (Table 7), a finding similar to that of Imtiaz (2018). In the TWS area, a drastic decrease (~5.5%) of forest area during 2016–2018 (Table 4 and Figs. 1, 3) was caused by the unplanned settlement of the refugees in 2017 (ISCG, 2019; Zaman, 2019). About 16% of refugees live within and/or in the vicinity of TWS (ISCG, 2019). Additionally, the ~0.5 million local and previously migrated refugees from the 1990s live in poverty and depend on TWS resources, similar to those living in HNP (Imtiaz, 2018). Extraction of forest resources, including illegal hunting of wild animals and conversion of land use from forest to agriculture, have become familiar phenomena in this area (Hossen and Hossain, 2018; Nishorgo, n.d.-a, n.d.-b; Sakamoto et al., 2017). Betal leaf (*Pan Pata*) cultivation is a popular agricultural activity, mostly (~80%) located on the western side of the TWS covering ~1000 ha and provides the only financial support to 200 households (Alam et al., 2015; Uddin and Khan, 2007). Deforestation is visible within the 5km RCCA buffer where ~22% of forested area has been converted to non-forest (~15%) and grassland (~7%) due to conversion to unplanned settlement and (desperate) extraction of firewood (Table 4; Fig. 3) (Haque, 2017; UNHCR, 2018).

Before the mass influx in 2017, a four-member family of the host community or of previously migrated refugees would each consume more than 100 kg firewood/month, accounting for 4.6% of monthly household expenditure at the Kutupalong and Balukhali area (Site A and B, Fig. 1) (IOM and FAO, 2017). However, by the end of 2017, ~800 000 refugees were been added to this community, collectively consuming 700 metric tons of firewood every day. To reduce the environmental impact of the refugee crisis, the FAO (FAO, 2019) initiated an intensive reforestation program by planting nearly half a million trees. The UNHCR (2018) has provided compressed rice husk fuel to 95 000 refugee families and offered hands-on training for the safe use of LPG and stoves for cooking. One cylinder of LPG is enough for a five-member family for one month, as viewed by the UNHCR (2018). But the refugees burn an average of 2 380 metric tons of firewood every month to address their deficiency of LPG for cooking. Despite responsibility for cooking (100%), having primary education (71%), and leading the family (~28%), females have no role in the decision-making process for domestic energy service provision (Bhatia et al. 2018; FGD and Field Survey). They have insufficient knowledge of the efficient use of various fuels and appliances to minimize energy consumption and no choice in selecting items for cooking, e.g., rice, pulse soup, and vegetables.

Bangladesh had planned to relocate 100 thousand refugees to Bhasan *Char* (Island) of ~40 km^2 (Fig. 1) with a Tk 2 312-crore (US$ 272.62 million) housing project that provides better housing conditions but with little opportunities for gardening and cultivation (Islam et al., 2021a). The houses are built four feet above the ground with concrete blocks and protected by a 3m high 13km long flood protection embankment, including 120 cyclone shelters which will be used as schools, medical centres, and community centres' (Islam et al. 2021a). However, Bhasan *Char* is a sandy island, which did not exist 20 years ago (Islam et al., 2021a). Geographically and geotechnically, it is very vulnerable, located at the mouth of Ganga-Brahmaputra-Meghna river system at the Bay of Bengal, about 35-40 km from Faujdarhat and Chairman Ghat, the nearest point of the waterway on mainland in Bangladesh (Fig. 1), it could be eroded and/or washed away by a flood and/or cyclone (Islam et al., 2021a). Currently, two or three severe cyclones hit coastal communities across Bangladesh every year, and to protect them from surge, at least a 6m high embankment plus 1m for expected sea-level rise by 2050 is necessary (Islam et al., 2021b). The United Nations (UN) and aid agencies argued that the isolation and natural hazard-prone nature of the island, mean that it would be like an open jail (Islam et al., 2021a). On 4th December 2020, refugees were started to move with 1 600 persons and by 3rd March 2021, 12 276 refugees were shifted to Bhasan *Char* even though many other refugees refused to move (Ahasan, 2020; Hossain, 2020; Islam et al., 2021a). However, discussion of whether this was voluntarily or forceful relocation, is out of scope for this study.

Before 2017, forest co-management by the Forest Department of Bangladesh and the Nishorgo network encouraged the local population to minimize forest resource dependence. (Alam et al., 2015) suggest that the co-management was successful with reductions in: firewood collection (21%), livestock grazing (27%), and hunting (80%), in the TWS area. However, many criticisms and limitations of co-management committees and their activities were revealed by other studies, e.g., unfair and non-transparent formation of the committees, local power and political interference, with almost no accountability (Islam et al., 2019; Rahman et al., 2012). Consequently, the success of co-management is questionable. In addition, large-scale transport infrastructure is planned to be built in this area as proposed by the ongoing Belt and Road Initiative (BRI), a project of the Bangladesh-China-India-Myanmar (BCIM) Economic Corridor. This will likely cause significant deforestation and land-use change. It will be interesting to compare subsistence deforestation related to the Rohingya settlement with that of large-scale infrastructural development, which may bring little benefit to local communities. It can be hoped that all of these hurdles can used as opportunities for environmental stewardship if all partner countries agree to develop BRI within a framework of strategic environmental and social assessments with high ecological standards. This approach would alleviate negative impacts on biodiversity and natural resources (Ascensão et al., 2018).

Anthropogenic impacts such as sudden and rapid unplanned settlement of refugees, and climate change effects, e.g., frequent and severe cyclones, raise questions of the sustainability of the HNP and TWS, and thus the forest ecology of this area.

It is acknowledged that the sample size with the questionnaires survey is not statistically significant in terms of the entire camp population. Small sample size may be considered as one of the limitations of the study. However, this survey is intended to provide insight into the general poverty of choice, and dependency of those living in the settlement on local ecosystem services, particularly forest resources, for firewood.

CONCLUSION AND FURTHER RESEARCH

All types of land cover during 2014–2016 remained the same. Similarly, land cover in 1995 and in 2018 is also almost the same. However, the forest degradation during 2016–2018 has mainly occurred near the settlement of a new group of refugees who migrated from Myanmar and the extraction of forest resources for use. The results of this study can be summarized as following:

- About 1746 ha is occupied for 80% of the refugees' settlement (estimated from shape area A and B in Fig. 1).
- About2880 ha deforestation during 2016-2018, an estimation of 22% decrease of forest area in the 5 km buffer zone of RRCA (Table 4) subtracted by 80% of the refugees' housing areas was caused by consuming forest product for building refugees' houses and burning firewood.
- The refugees are still burning an estimated 2 380 metric tons of firewood every month for cooking to address the deficiency in UNHCR's supply of LPG.
- Deforestation (~5.5%) at the TWS area during 2016-2018 was caused by refugees' settlements and their extraction of forest resources (Table 4).
- Deforestation (~3%) at the HNP might not be linked to the recent refugees' migration and their settlement (Table 4).

In general, forest degradation in the study area is predominantly caused by forest resource extraction, illegal hunting, and conversion to agricultural use. Co-management of forest resources is a useful tool to minimize the dependence on forest resources, but, the practical experience of co-management in this area requires transparency and accountability. Notably, it is found that deforestation caused by refugees' settlement during 2017–2018 is almost equivalent to the effect of severe tropical cyclones during 1991–1995.

Further study is recommended on efficiency of domestic energy use, particularly of the refugee households; to identify reasons LPG supplies are insufficient. This approach could lead to an effective training programme on the efficient use of LPG on a household or community basis, with the aim of ensuring LPG supplies are sufficient and eliminating the burning of firewood and selling of rations to pay for fuel. This study also identified a need for comparatively durable housing materials be provided to reduce dependence on forest resources to maintain dwellings.

The future sustainability of forest ecology in this area depends on effective co-management of forest resources. It is essential that further research on BRI project impacts be conducted to inform sustainable environmental practices and minimize impacts. If that research cannot be executed, quickly and effectively, the biodiversity and sustainability of forest ecology will be destroyed. The effects of climate change, which, given the geographical location, will likely increase the frequency and severity of tropical cyclones hitting this area (Islam et al., 2021b); as well as future unplanned immigration settlement and their unsustainable use of forest resources, will further the destruction of these ecosystems.

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AUTHOR CONTRIBUTION

MTI conceptualized this study, collected and processed remote sensing data. MTI conducted questionnaire survey which was conceptualized and facilitated by SLH. MTI conducted statistical analysis, prepared tables, maps and figures and wrote manuscript. SLH, MC, KHK provided specialist interpretation and reviewed the manuscript.

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